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Zipping Dielectric Elastomer Actuators for microfluidics

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ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Abstract

One of the goals of microfluidics is to bring a whole laboratory processing chain on a few square centimeters, Lab-On-Chips (LOC). A wide class of LOC use the pneumatic deformation of silicones to selectively open or close channels. But these current LOCs require many heavy and power-consuming off-chip controls like pneumatics, pumps and valves, which keep the small chip bound to the lab.

Miniaturized Dielectric Elastomer Actuators (DEA) are excellent candidates to make LOC truly portable, since they combine electrical actuation, large stroke volumes and high output forces.

We report on the use of zipping actuation applied to DEAs for an array of three mm-size zipping chambers, forming a peristaltic pump. Unlike the traditional actuation mechanism of DEAs that squeezes an elastomer between 2 compliant electrodes, zipping DEAs use electrostatic attraction between a compliant electrode and a rigid one. The membrane is pulled out-of-plane into contact with the grounded sloped chamber walls.

A zipping analytical model was developed to predict the actuator's behavior and help for the design (chamber dimensions, silicone type and thickness…). Three chambers connected by an embedded channel were wet-etched into a silicon wafer and subsequently covered by a silicone membrane, on which we pattern a compliant electrode by Au-ion implantation [1]. We first varied the chamber dimensions to assess the model. These measurements show a very good agreement with the model, but breakdown occurs before predicted. We observe that the central part is not as flat as assumed in the model, and this effect is quantified for soft silicones.

In order to zip down completely the membrane in 525 µm deep chambers, we compare two silicones: CF19 from Nusil (Young's modulus of 1 MPa and breakdown strength around 220 V/µm) and Silbione LSR4305 from Bluestar (0.2 MPa and about 100 V/µm). Static deflections up to 300 µm before breakdown were achieved with the CF19, but only the half with the LSR4305. This is attributed to the fact that the implantation-induced stiffening of the membrane [1] is more important on a softer polymer, limiting the increase in strain due to the use of a softer silicone.

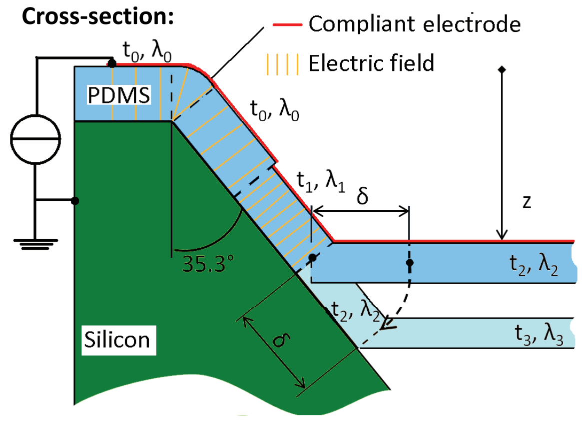
Model

We model the zipping depth z in function of the voltage by an iterative computation of the elastic and electrostatic energies followed by an extraction of the energy minima. [2]

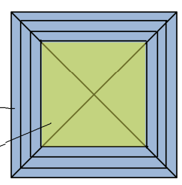
Main hypothesis:

- Electric field on the non-zipped part negligible
- Bending energy neglected
- No slipping

Cross-section:



Top view:



Elastic energy:

$$E_{EL} = \sum_n W_{s,n} \cdot V_n + W_{s,flat} \cdot V_{flat}$$

Electrostatic energy:

$$E_{ES} = -\frac{1}{2}\varepsilon_0 \varepsilon_r U^2 \sum_n \frac{A_n}{t_n}$$

Total energy:

$$E(z) = E_{EL} + E_{ES}$$

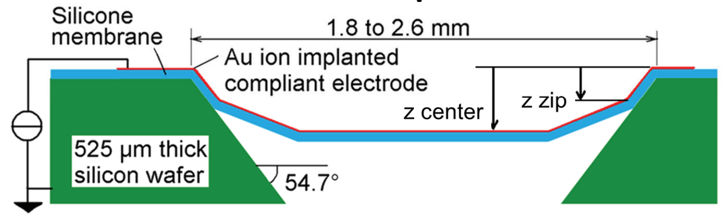
W: elastic energy density
V: volume
A: area
t: membrane thickness
U: voltage

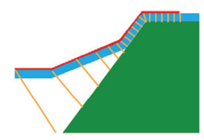
The model predicts:

- A zipping jump above a threshold voltage
- maximal deflection nearly independent on the membrane thickness

Non-ideal membrane shape

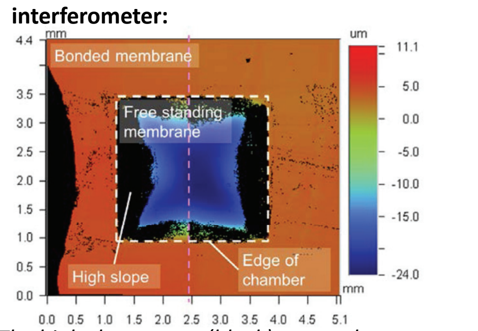
The suspended part of the membrane is not flat





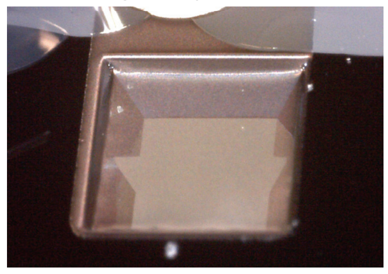
Schematic view of the electric field (orange)

z center **measured with a white light interferometer:**



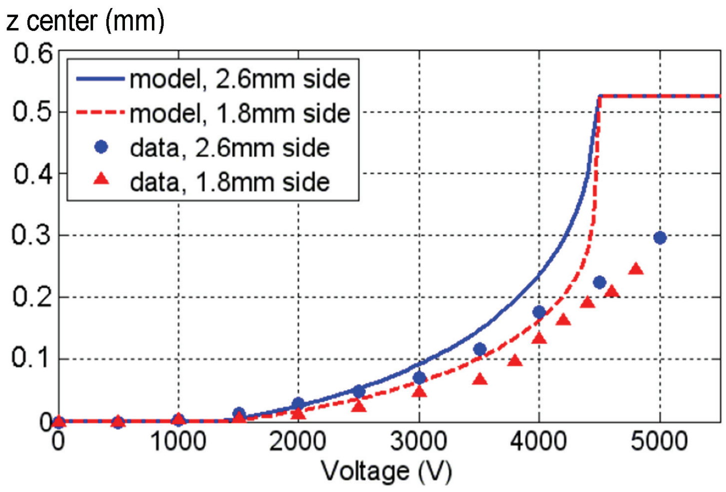
The high slope zones (black) cannot be measured

z zip **measured with an optical microscope and an image analysis software:**



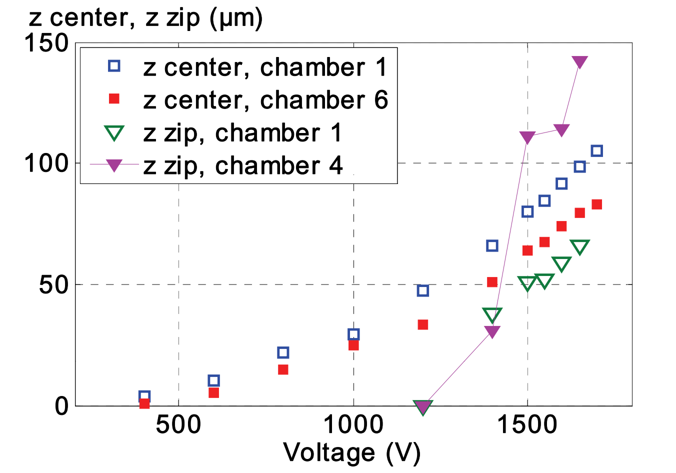
The contact of the membrane on the sidewalls is clearly visible

Maximal *z center* of 300 µm with Nusil CF19



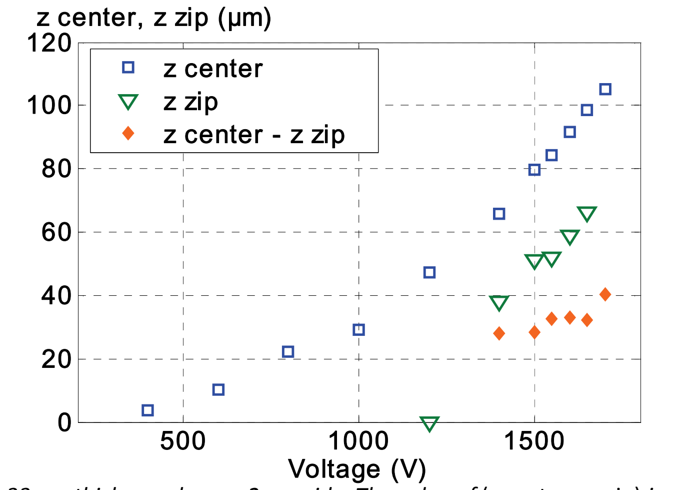
53 µm thick membrane, plotted with the design model [2]. The deflection limit is imposed by the wafer thickness.

Maximal *z zip* of 140 µm with LSR4305



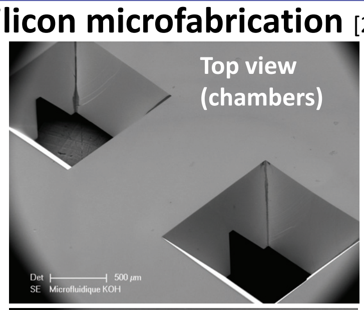
33 µm thick membrane, 2mm side. The mechanical properties of the implanted LSR4305 membrane are not yet measured, preventing the use of the model. The maximal deflection on chamber 4 is achieved thanks to optimal implantation parameters.

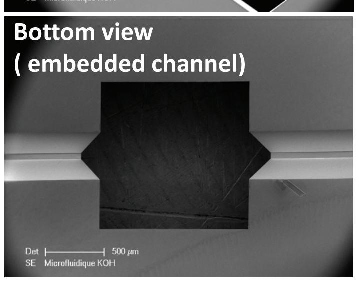
Comparison between *z center* and *z zip* with LSR4305 on the same chamber



33 um thick membrane, 2mm side. The value of (z center – z zip) is nearly constant and about equal to the membrane thickness.

Silicon microfabrication [2]

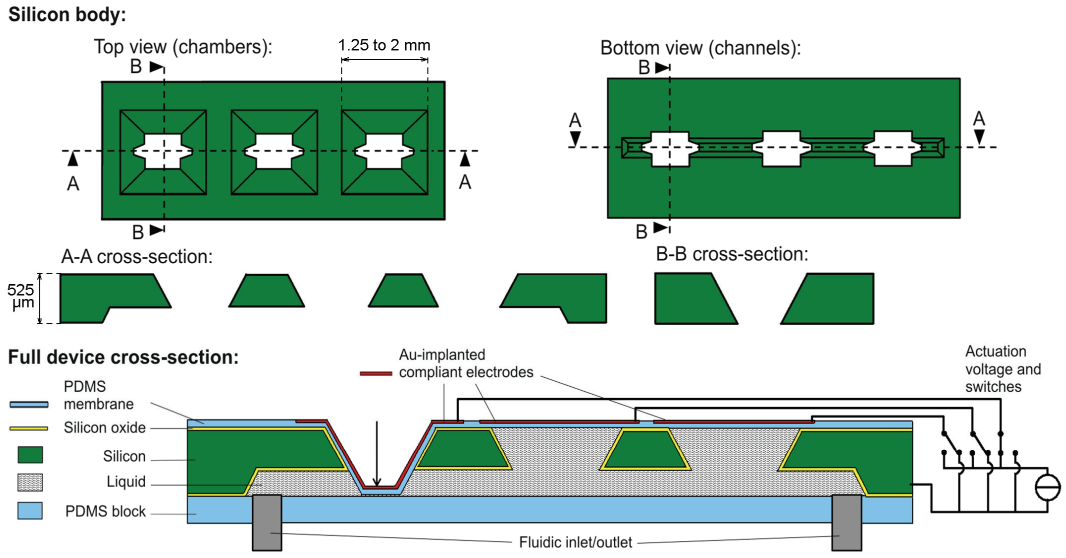




Scale bar : 500 µm

Micropump

Three chambers in series with an embedded channel



Conclusion

The novel miniature DEA zipping device presented here is able to deform an elastomer membrane out-of plane by attracting an Au-ion implanted compliant electrode toward a rigid counter-electrode. This rigid electrode is the sloped chamber wall itself.

A model was built and shows good agreement with the first set of results, assuming a completely flat suspended part in the middle of the chamber.

Two different silicones are investigated in order to achieve a complete deflection in 525 µm deep mm-size chambers. It is found that the use of the stiffer but more resistant to breakdown polymer achieves twice the deflection of the softer one, up to 300 µm on 2.6 mm side chambers.

Zipping DEAs are promising candidates to replace the pneumatically-actuated microfluidic chambers and valves, although the breakdown limit is critical. Solutions include new chamber geometries, more compliant electrodes or zipping with the electric field across a solid dielectric.

Acknowledgments

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References

[1] Rosset S., Niklaus M., Dubois P., Shea, H. R., "Large-Stroke Dielectric Elastomer Actuators With Ion-Implanted Electrodes", JMEMS, vol.18 no.6 (2009)

[2] Maffli, L., O' Brien, B., Rosset, S., Shea, H. R., "Pump it up", Proc. SPIE Vol. 8340, 83402Q, doi 10.1117/12.914831 (2012)